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14. ABSTRACT
The effects of intermittent work patterns and funding on the costs of ship repair and maintenance were modeled for the San Diego region in 2002 for Supervisor of Shipbuilding San Diego. One of the shipyards that participated in the study requested that CACI adapt the general regional model to a more specific, proprietary model for proposal development purposes. This paper reports on the development of the shipyard workflow model, as well as its validation and verification using historical data. The model allows the shipyard to experiment with different patterns of work, availability schedules, hours, repair availability length and start dates to determine the overall loading of the shipyard's 17 trades over one or more fiscal years. It incorporates human resources, scheduling, financial, infrastructure and work sectors. Important factors considered in the model are volume, productivity, experience, man-day rate and error rate. The model estimates work to be scheduled, actual work accomplished, workforce used and the cost to the government.

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Ship Repair Workflow Cost Model

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ABSTRACT

The effects of intermittent work patterns and funding on the costs of U.S. Navy ship repair and maintenance were modeled for the San Diego region in 2002 for Supervisor of Shipbuilding and Repair (SUPSHIP) San Diego. One of the private shipyards that participated in the study requested that CACI adapt the aggregated regional model to a more specific, proprietary model. The goal was to use insights gained from the model to better understand and control cost. This paper reports on the development of the private shipyard workflow model. The model allows the shipyard to experiment with different patterns of work, availability schedules, hours, repair availability length and start dates to determine the overall loading of the shipyard's 17 trades over one or more fiscal years. It incorporates human resources, scheduling, financial, infrastructure and work sectors. Important factors considered in the model are volume, productivity, experience, man-day rate and error rate. The model estimates work to be scheduled, actual work accomplished, workforce used and the cost to the government.

INTRODUCTION

Estimation of the effects of workload variation on the cost of work was the topic of a simulation modeling study commissioned by Commander, Naval Surface Force U.S. Pacific Fleet (COMNAVSURFPAC) in cooperation with SUPSHIP San Diego. The study focused on the five largest San Diego private shipyards or Major Ship Repair (MSR) contractors. CACI was the prime contractor for the study that included Brian Barry Consulting, Inc. as the primary subcontractor. The results of the study were a System Dynamics model of "Waterfront Workflow" developed in early 2002.

The basic workflow model was well received by the Navy with high-level presentations provided to the Ship Maintenance community and to the Chief of Naval Operations later that summer. Model results clearly demonstrated the impact on cost and efficiency when ship repair activities are level loaded. Level loading attempts to remove excess variability in the pattern of work delivery to a repair facility. COMNAVSURFPAC took action later in 2002 to reduce that variability in shipyard loading by increasing the use of the Navy's Continuous Maintenance program and through

stricter enforcement of work cutoff dates. The model clearly showed the effects Fleet schedule perturbations had on cost and was used by the Naval Sea Systems Command (NAVSEA) to estimate the impact of planned maintenance schedule changes caused by Operation Iraqi Freedom on maintenance budgets upon force reconstitution.

Additionally, the basic model was further expanded in 2003 with the development and validation of a workflow model for Tidewater/Hampton Roads Virginia. A government sector shipyard model for the Norfolk Naval shipyard was also developed in 2003. Work is ongoing to develop additional government shipyard models as well as models for other commercial port repair regions serving the Navy.

Southwest Marine (SWM)

Southwest Marine (SWM) is a member of United States Marine Repair (USMR), a wholly owned subsidiary of United Defense Industries, with facilities in Norfolk, VA, San Diego, San Pedro and San Francisco, CA, Ingleside, TX, and Pearl Harbor, HI.

United Defense is a leader in the design, development and production of combat vehicles, artillery, naval guns, missile launchers and precision munitions used by the U.S. Department of Defense and allies worldwide and is America's largest non-nuclear ship repair, modernization and conversion company.

Southwest Marine was one of the MSRs that participated in the original workflow study. Early on they realized that modeling results could help them become more competitive by better understanding the impact on cost caused by workload delivery patterns and by better understanding the mechanics involved in resizing the workforce. A tailored model would allow them to experiment with revised business practices and develop better forecasts. Results could be used to negotiate with customers (primarily, but not wholly, the Navy) when variability of future workload patterns induced higher costs. Greater stability also reduced workforce churn to the benefit of both employees and management.

Since development and validation of the model Southwest Marine has used it to estimate costs for at least two major contract proposals.

BACKGROUND

As mentioned earlier, the SWM model was adapted from a macro-level model that considered total Navy ship repair workload aggregated over multiple commercial ship repair activities in the port of San Diego. The basic concepts and structure of that model are preserved in the SWM model. Although a significant amount of work was done to adapt the basic model, that work did not change the basic nature of the new model. Major changes occurred in three primary areas.

First, the model incorporates the actual business rules used by the shipyard to forecast and schedule work.

Second, the exact human resource structure and personnel adjustment practices for the shipyard are modeled, including disaggregation of the workforce into seventeen explicit trades, each with a different skill profile.

Finally, costs are calculated using actual shipyard business practices and cost data. Because much of what was done involved business sensitive information and because the model is still in use today, we are restricted from describing some portions of the work. The emphasis of the paper will be on the underlying concepts and structure of the basic model. Modifications to it and subsequent validation will be discussed to the greatest extent possible.

THE BASIC MODEL

When the Navy assigns work to a shipyard, the direct labor workforce (that portion of the total workforce doing hands-on production) is adjusted to match the assigned loading. This adjustment does not occur instantaneously and the workload rarely remains constant. As a consequence the normal shipyard workforce is routinely either overloaded or underloaded.

In San Diego, the average labor workforce adjusts to workload in three to five weeks. Because hiring takes much longer to accomplish than layoffs, moving downward occurs more quickly than moving upward.

When workload exceeds normal workforce capacity, a shipyard can employ overtime to increase that capacity. In San Diego, the shipyards prefer to sustain a workforce that is slightly overloaded. Specifically, they wish to sustain a ratio of the workload to the workforce of 1.05. This loading ratio provides an average of two hours of overtime per week for each worker and cushions the shipyard somewhat from the need to perform layoffs when workload is less than capacity. Experience shows that sustained low levels of overtime do not impact productivity. Added cost (from overtime differentials) is also usually less than the cost to resize the workforce.

A workforce requires infrastructure to support it. As the size of the workforce changes, the shipyard adjusts the size of that infrastructure (capacity) to match it. As used in the model, this infrastructure comprises facilities, equipment and that portion of the (indirect) staff that supports the production workforce (e.g., executives, administrators, accountants, designers, and purchasing agents).

When the infrastructure is ideally sized, it is the minimum needed to support the existing workforce (in terms of man-days/day) without productivity losses. The three key variables: *workflow*, the *current labor workforce*, and the *infrastructure* can all be evaluated in terms of man-days per day. A man-day is defined as the amount of work one person can perform in a nominal eight-hour workday.

Infrastructure additions are expensive. Once lost, infrastructure is hard to replace. Therefore, management is reluctant to change capacity, and infrastructure adjustments occur much more slowly than do adjustments to the labor workforce. Because loading is constantly changing and the production workforce reacts to loading, it is normal for the ratio of the workforce to the infrastructure to be either higher or lower than the ideal value (defined as 1.0.)

Figure 1 describes the interactions between workflow, workforce and infrastructure. It is a significant simplification of the actual model structure. Not shown are the details of the labor workforce or the factors that influence the speed with which the workforce and the infrastructure are changed. Nevertheless, Figure 1 captures the essential dynamic properties of the system as well as the principal factors that control man-day rates and productivity. These factors do not operate linearly. For example, the effect of overloading the infrastructure on productivity is not linearly related to the degree of overloading. The analysis team devoted considerable effort to estimating these non-linear effects. The next section describes non-linear factors that influence the man-day rate, productivity and the production error rate.

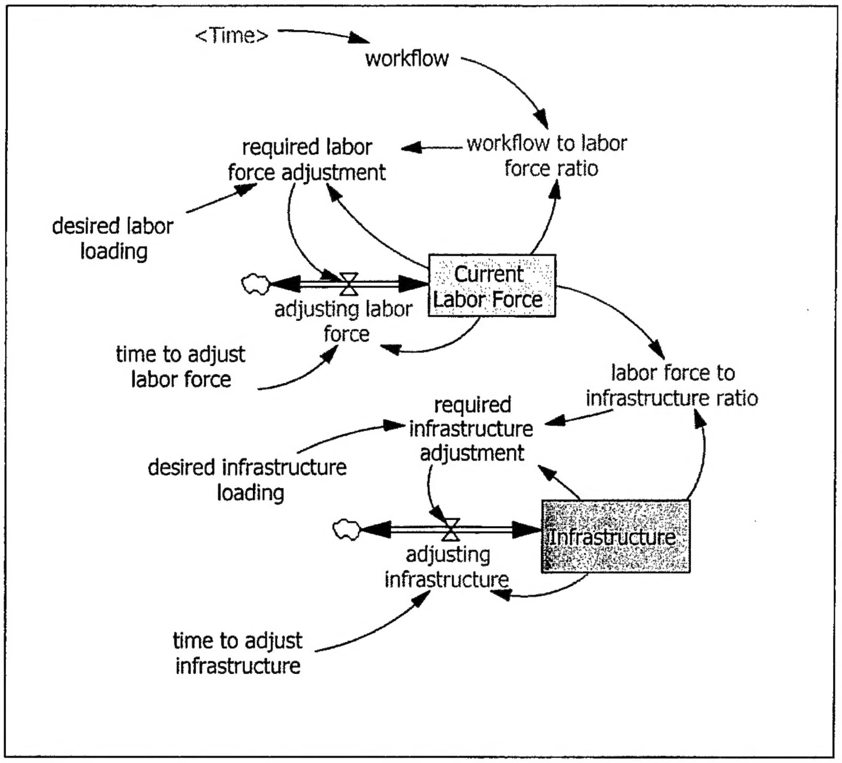

Figure 1: Workforce and infrastructure reactions to workload.[A]

MAN-DAY RATE

A nominal man-day rate was calculated based on prevailing wages in the San Diego area and the cost of the infrastructure when the shipyard is operating at its most efficient loading. During simulations, the model continually recalculates the man-day rate as key variables adjust dynamically to the workload assigned by the Navy.

Overloading the Labor Force: When the assigned workload (in man-days per day) is larger than the labor force, overtime and sub-contracting add cost. The man-day rate will increase.

Underloading the Labor Force: When the assigned workload is smaller than the labor force, the underemployed labor generates increased overhead costs. The man-day rate will increase.

Labor to Infrastructure Ratio: As the Labor to Infrastructure Ratio increases from its minimum plausible value to its maximum plausible value, the man-day rate decreases. Increased loading permits infrastructure costs to be allocated across a larger base of revenue, thus reducing the man-day rate across the full range of plausible loading. (This seeming benefit can be offset by productivity losses and error rate increases as described below.)

Average Salary: As the ratio of skill levels change, the average salary of the workforce changes. This can lead to increases or decreases in the man-day rate.

Adjusting the Labor Force: Both laying off and adding workers costs money. Labor force adjustments increase the man-day rate.

Adjusting the Infrastructure: Increasing or decreasing the infrastructure is expensive. Infrastructure adjustments increase the man-day rate.

PRODUCTIVITY

Work is accomplished at some nominally defined rate. Productivity adjusts that rate either up or down depending on a similar set of factors:

Labor to Infrastructure Ratio: As labor increases relative to infrastructure, a point is reached where productivity begins to decline. This value is defined as the most efficient infrastructure size and is the point where the ratio of the labor force to the infrastructure (expressed in man-days/day that can be supported) equals 1.0. As the ratio moves above 1.0, productivity declines. Insufficient planning assets, competition for equipment and facilities, strained managerial resources, and similar factors are symptoms of inadequate infrastructure support.

Infrastructure Fatigue: In addition to the instantaneous effect of infrastructure overloading described above, further productivity declines occur whenever a pattern of overloading the infrastructure is sustained for a prolonged period of time. Tired people are less productive.

Labor Force Fatigue: The labor force may also become fatigued from sustained overuse (from overtime.) A fatigued workforce is less productive.

Worker Experience: If the labor force is increased quickly, then average experience decreases. Less experienced workers are less productive.

Anticipation of Layoffs: The workforce is both knowledgeable of and sensitive to near-term workload fluctuations. Productivity declines whenever layoffs are imminent.

ERROR RATE

The production error rate is not constant. Errors result in more workload through rework. It reacts to a third set of influences:

Labor to Infrastructure Ratio: Supervisory resources are stretched as the labor force increases relative to the infrastructure. Stressed purchasing agents make errors at an increased rate. Tools that are normally unused because of their deteriorated condition are pressed into service. These and similar factors cause a stressed infrastructure to induce an increased rate of production errors.

Infrastructure Fatigue: As described above, fatigue causes productivity to decline. Simultaneously, it causes more errors to be made.

Loading Ratio: As the ratio of the workload to the labor force increases, workers feel the pressure to complete jobs faster. The error rate increases.

Labor Force Fatigue: Sustained increases in the loading ratio cause workers to work overtime over prolonged periods of time. A fatigued labor force is more error-prone.

Worker Experience: Less experienced workers make more errors. As experience levels decline, more experienced workers shift from production to supervisory and administrative roles. This compounds the effect on the error rate: a decline in experience levels not only results in more "rookies" on the job, it also moves experienced workers away from production and towards administration.

These factors operate on the man-day rate, productivity and the error rate simultaneously. The net influence of a specific pattern of work is almost impossible to predict (at least in quantitative terms) without running a simulation. The net movements in man-day rate, productivity and the error rate reflect more than the present ratio of the workload to the workforce and of the workforce to the infrastructure. They also reflect past loading

patterns that have induced current levels of fatigue and worker experience. Finally, they reflect management and workforce anticipation of future events.

ADDITIONAL CONCEPTS

In modifying the basic model to simulate a specific shipyard's behavior in response to workload changes, some concepts described above needed to be revised and new concepts added based on the specific SWM user's business rules instead of the more general consensus rules used by the port shipyard community as a whole.

Overtime was changed to a dynamic variable but was constrained to be no greater than 20%.

The shipyard identified its desired Journeyman/Apprentice/Helper/Laborer ratios and described the precise business rules for its human resources (HR) structure. The HR structure at the shipyard included seventeen (17) trades (welders, pipe fitters, painters, etc.) and four labor categories, Journeymen, Apprentices, Helpers and Laborers.

Southwest Marine performs work forecasting and scheduling according to specific proprietary business rules based on past experience. The specific work scheduling practices were extracted from subject matter experts and used to modify the base model.

Dynamic Overhead Rates based on volume were provided by the shipyard to replace the overloading and under loading constants in the original model.

WORK PERFORMANCE

When the Navy schedules any repair period (called an availability) for a ship, the work package has an expected <u>size</u> (Mandays of work to be accomplished) and <u>duration</u> (weeks). The shipyard uses this information to predict, schedule and manage the resultant workflow in the yard.

Southwest Marine has an extensive work history database that provides good estimates of the percentage of each work package that will be assigned to each trade.

The total work package is broken into equal weekly segments and then multiplied by a work profile vector. The work pattern front-loads the work towards the first half of the availability by as much as 50% (depending on the trade.) The resultant weekly work packages are assigned to a weekly work bin based on the start date of the availability.

Growth is estimated and added to the package based on historical data by trade and week of the availability. Continuous Maintenance work package estimates are also added to the weekly work package. The week of the availability is indicated by the subscript "FC" in model equations.

This logic is shown in Figure 2 as the *Work Pending* variable, where:

```
Work Pending = INTEG(
(scheduling[trades,FC] * New
Work Pattern[trades,FC]) +
(Work Pending[trades,FC] *
pending growth rate))
```

<u>Note</u>: In comparing the integration equation with the figure 2, note that the work outflow *releasing* does not appear in the above equation. This is not an error. The *Work Pending* stock serves as a pseudo aging chain. The variable *age work*, uses the VENSIM® <u>SHIFT IF TRUE</u> function to empty the stock and set the value of *releasing*.

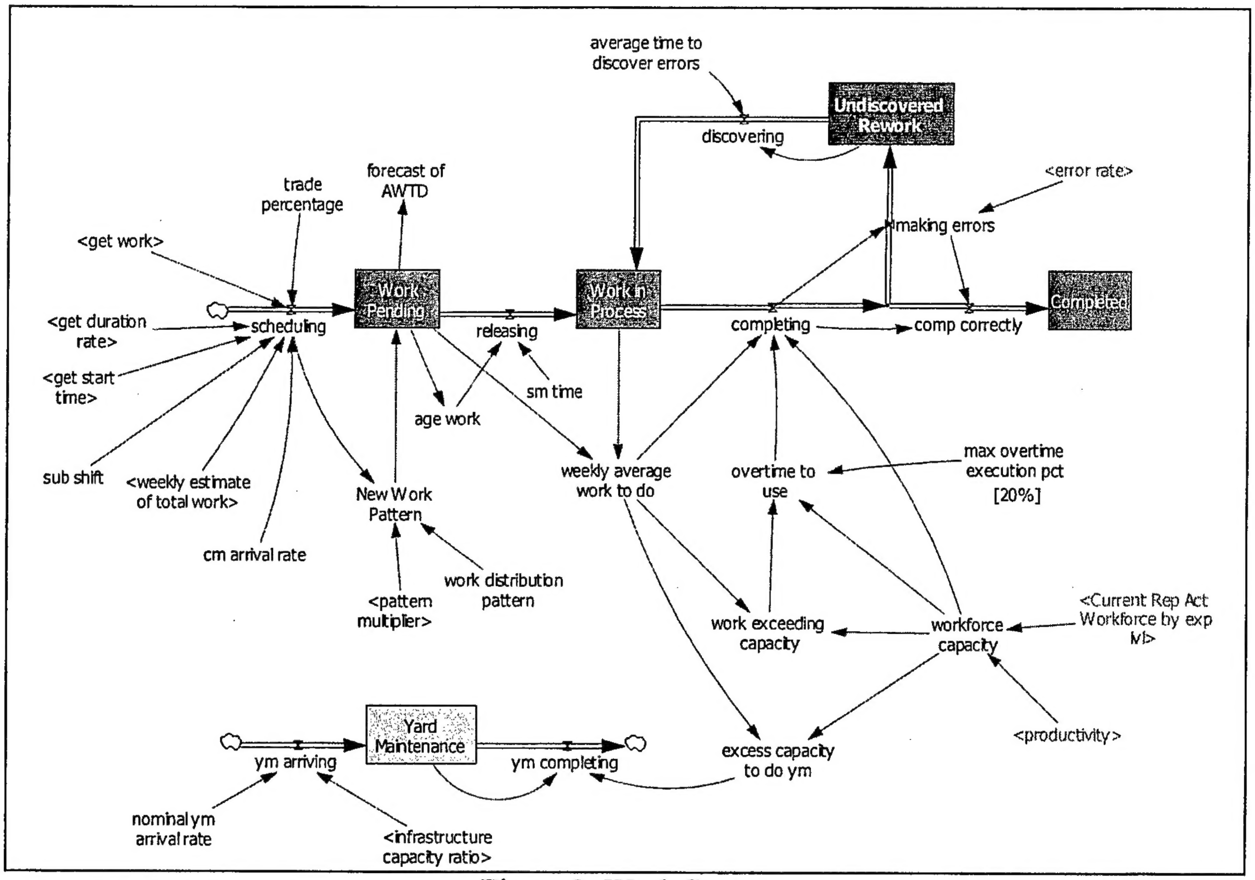

Figure 2: Work Sector

In this fashion, work for each trade, pending for a given week, is estimated and used for scheduling and calculation of the weekly workload as it is released into the Work in Progress stock.

Each week, new work is added from the *Work Pending* stock to the *Work in Process* stock. The work remaining in the *Work in Process* stock reflects the work that was previously released but not completed and any additional work (rework) caused as a result of the dynamic *error rate.*

This work on hand is then compared against future work pending. The shipyard's practice was to use a monthly projection (three weeks of future work and the current week's work) to calculate the *weekly average work to do.*

This logic permitted some internal (or self) level loading by the yard if capacity permitted. The yard could work ahead in an attempt to reduce a large influx of work or reduce tempo in the face of a predicted future near term drop in work. This logic along with a dynamic calculation of *overtime to use* and *workforce capacity* is used to estimate the value of *completing.*

The current workforce capacity is used to determine how much work is completed by including *productivity.* Productivity can vary widely as discussed previously and needs to be considered when projecting work accomplishment.

When workforce capacity exceeds the work to be done, excess capacity is used to catch up on yard maintenance that is deferred during times of high loading.

As workload permits, yard maintenance is accomplished with excess capacity. Therefore yard maintenance is predominantly

performed during lulls in loading. For example, the traditional holiday period in December tends to be loaded more lightly and is an ideal time for yard maintenance.

Overtime to use is constrained by *maximum overtime execution pct*, which was set for most runs at a upper limit of 20%. In this manner, the shipyard can decide to work overtime to get ahead of a coming surge. Twenty percent was considered a reasonable limit on overtime because at overtime rates much above that, most benefits in completing work become lost due to a decrease in productivity (due to fatigue) and increase in the error rate.

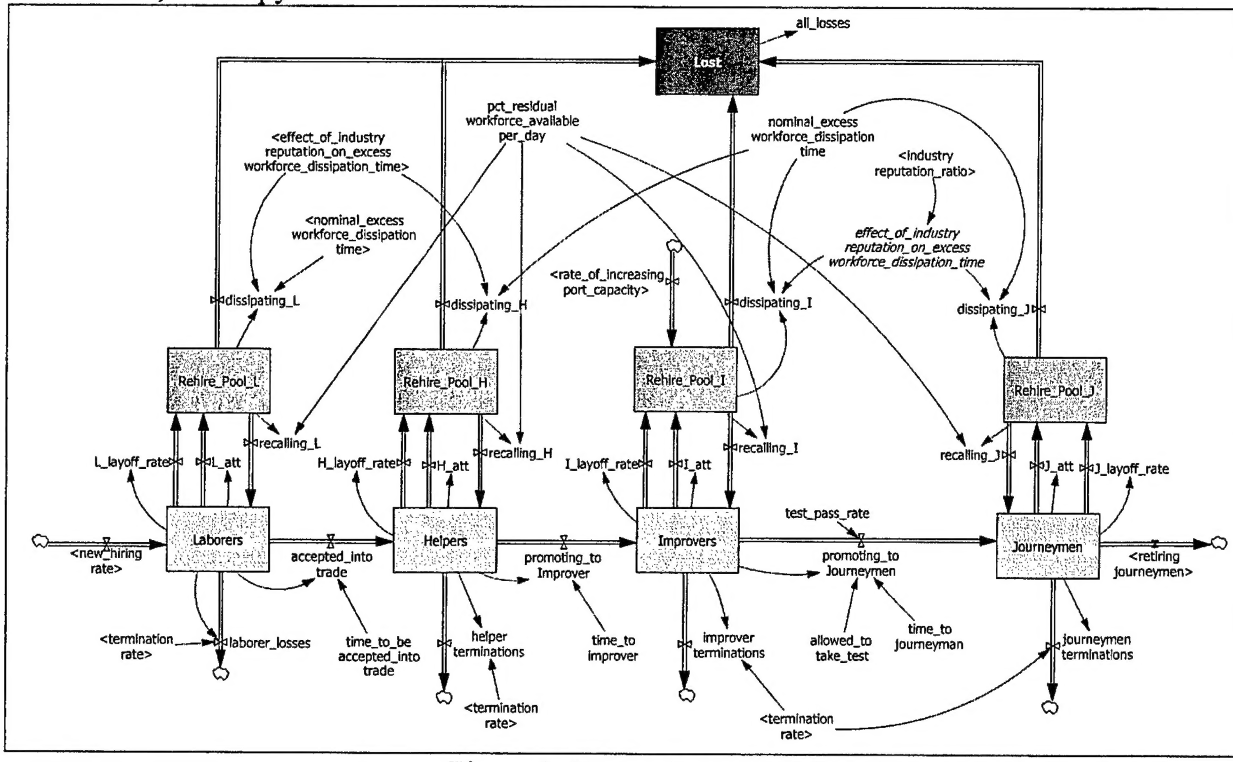

Figure 3: Human Resources Sector

HUMAN RESOURCES

Figure 3 depicts the human resources structure of the shipyard and the surrounding community. This section greatly expanded the detail found in the basic model. There are continuous flows of people through the personnel system as the pattern of work changes. For example, when there is more work than workers, the shipyard will attempt at first to work overtime while attempting to find more labor. Additional labor could consist of any combination of recalled, new or subcontracted employees.

When the work pattern decreases over time, some people are laid off. They flow into the rehire pool where they stay until recalled or hired by another shipyard or even another industry. The rate of dissipation out of the rehire pool is based on the recent history or accrued reputation of the shipyard for layoffs.

One of the factors included in the hiring logic was the concept of most efficient workforce mix or ideal workforce ratio. It represents the percent mix of Journeymen, Improvers, Helpers or Laborers by specific trade. For example, see Table 1, where in the painters trade (Dept. 202) the ratios are

Journeymen 0.53, Improvers 0.11, Helpers at 0.35 and Laborers at 0.00 with the remaining one percent assigned to trade supervision and management. Whereas for the ship-fitter trade (Dept. 205) the ratios are: Journeyman 0.66, Improvers 0.08, Helpers 0.04 and laborers 0.22.

When required to increase the size of the workforce, Southwest Marine will first attempt to recall previously laid-off workers from the rehire pool. The longer the time between hiring periods the fewer people will respond to a recall, especially at the journeyman levels.

Separately, the shipyard can devote energy and funds (at additional cost) to attract new workers into the community. This is represented by the variable, *rate of increasing port capacity*. See Figure 5. This availability of personnel for hire in the port is governed by two constants, *labor capacity growth rate that causes normal recruiting effort* and *time to increase capacity* and two non-linear effects, *effect of growth rate ratio on growth rate per week* and *effect of industry reputation for layoffs on growth rate per week*. These are described later in the effect graphs section of the report.

The logic for advancement within the shipyard trades from laborer to helper to improver to journeyman is explicitly modeled. Historical termination and attrition rates were used but hiring and recalling logic were explicitly and dynamically modeled with the shipyard's business logic.

Skill Level \ Dept	202	203	204	205
Laborers	0.00	0.02	0.00	0.22
Helpers	0.35	0.17	0.18	0.04
Improvers	0.11	0.22	0.17	0.08
Journeymen	0.53	0.58	0.64	0.66

Table 1: Workforce Ratios

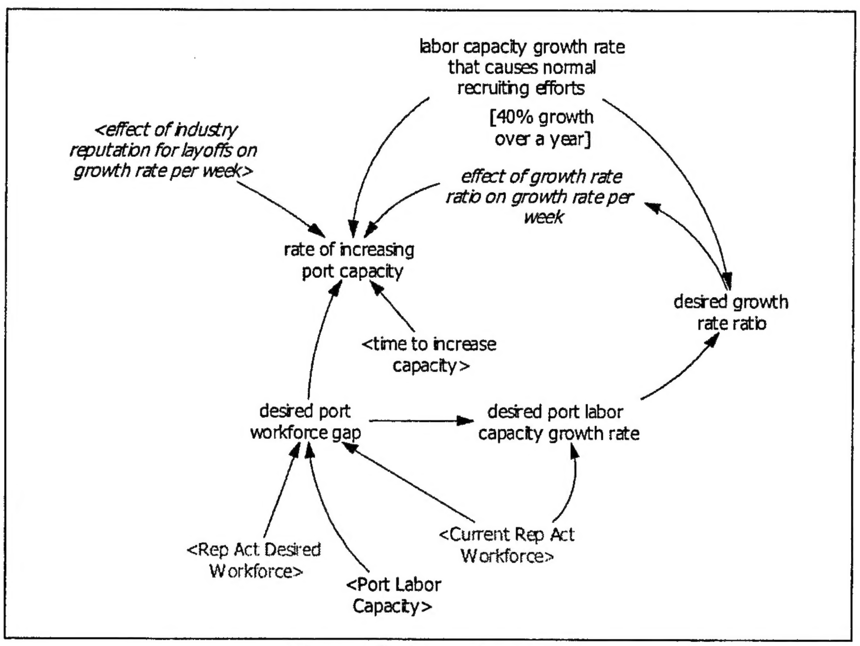

Figure 5. Port Capacity

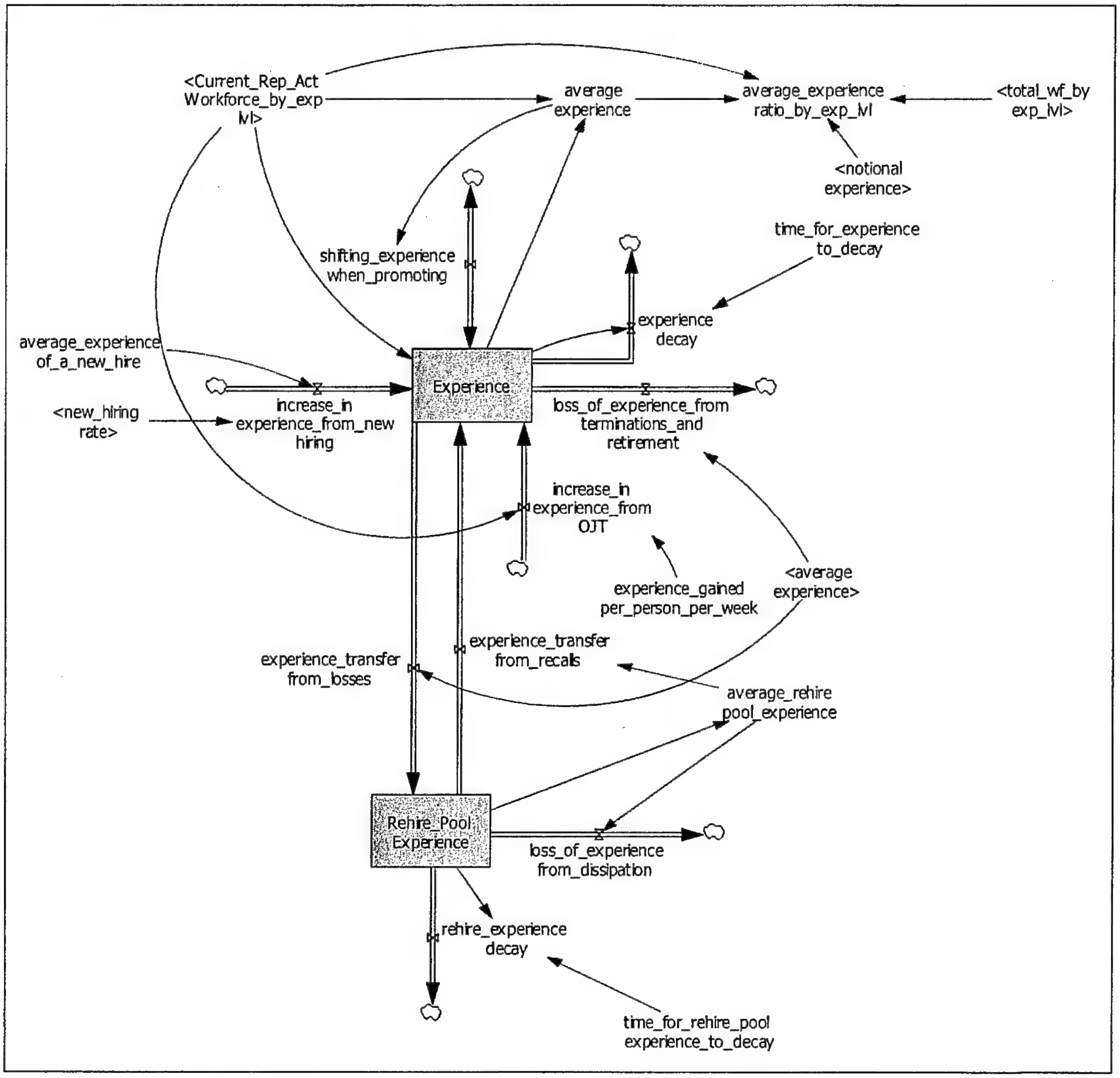

Figure 6: Experience Sector

EXPERIENCE

Figure 6 details how experience is accrued as the workforce is reshaped to fit the work pattern. Experience is gained every day. Experience is lost whenever anyone leaves the shipyard.

There is some nominal level of experience that is required for a certain level of productivity and error rate that is assumed based on the "ideal" workforce mix. This mix differs based on trade as described above.

As hiring increases to match workload the average experience in the shipyard decreases with a resultant loss in productivity and an increase in error rate. This effect is offset somewhat by a reduction in the man-day rate.

When layoffs occur, people with less seniority and experience tend to leave first leaving the more experienced journeyman behind. Average productivity increases with very little increase in penalty error (caused by

experience level), however the cost per man-day also increases.

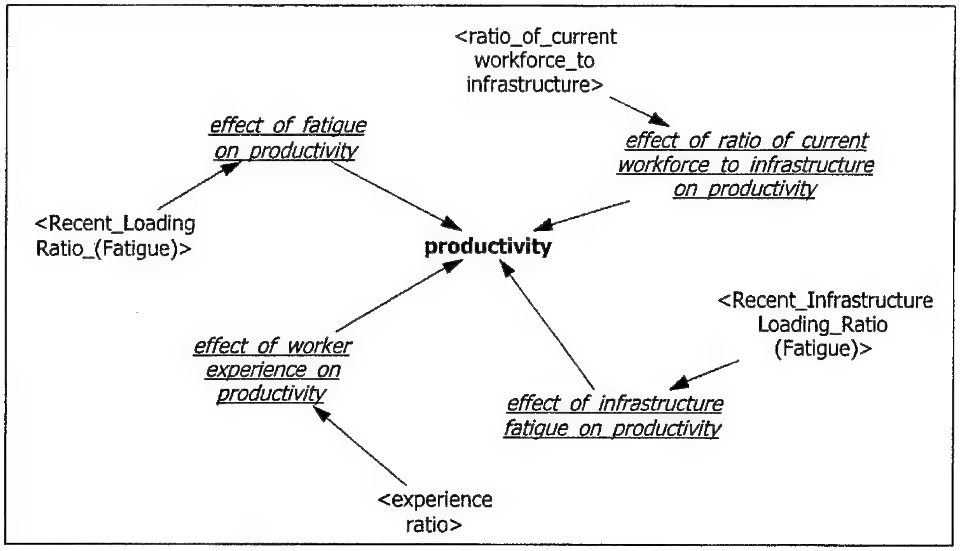

Figure 7: Productivity Sector

PRODUCTIVITY

Productivity as discussed above and as shown in Figure 7 is comprised of four factors: worker fatigue, infrastructure fatigue, worker experience and the support received from the infrastructure.

Productivity determines how much work gets done above or below some nominal rate. Figure 8 shows the model relationships and how the productivity multiplier is used in subsequent model calculations. Later in the model the amount of work completed (*completing*) is used to ultimately calculate the total cost.

Figure 9 shows the non-linear functions that control productivity that were developed in the basic workflow model based on a consensus of the San Diego MSR community. These same effect graphs were later validated and accepted by the Hampton Roads/Tidewater area MSRs.

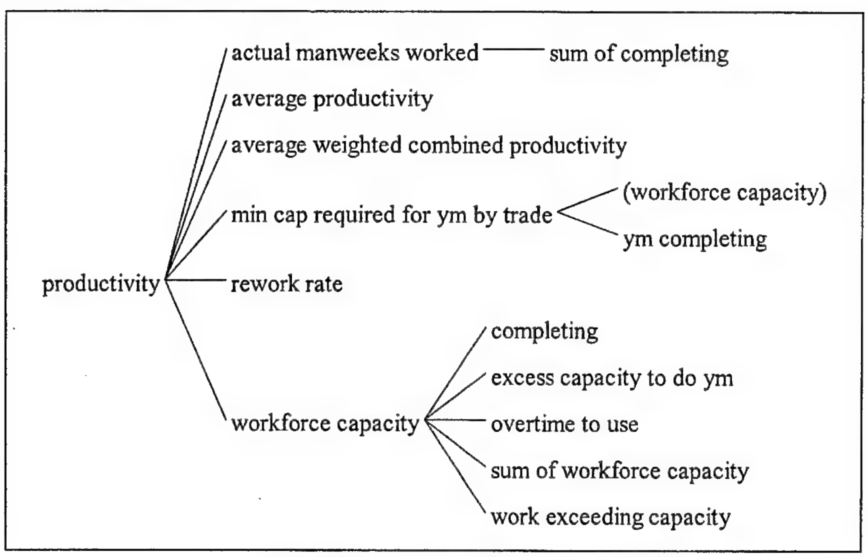

Figure 8: Productivity Uses Tree

EFFECT GRAPHS

There are seventeen (17) non-linear effect graphs used in the model. These normalized lookup functions were either developed with the shipyard based on its own proprietary information and historical data, or were accepted from the work performed in the basic workflow model.

- Four drive productivity
- Five control the error rate.
- Two control port capacity growth.
- Two effect attrition.
- One effects the dissipation of the workforce after layoff.
- One effects the decision time for adjusting the workforce.
- Two effects on Overhead Costs.

Effects are expressed as the *effect of X on Y*, where the look up variable is found on the x-axis and the effect multiplier on the y-axis. For example, the top left graph in Figure 9 representing the *effect of fatigue on productivity* is used as follows. When calculated the effect variable (or graph) receives an input value, in this case the current value of fatigue. Assume *fatigue* = 1.5 is the x-axis value. The corresponding value on the y-axis is the output or returned value. In this case the *effect of fatigue on productivity* = 0.9431. Used as a multiplier, this would reduce overall productivity. When the workforce is fatigued (i.e. is > a nominal value of one, productivity decreases.)

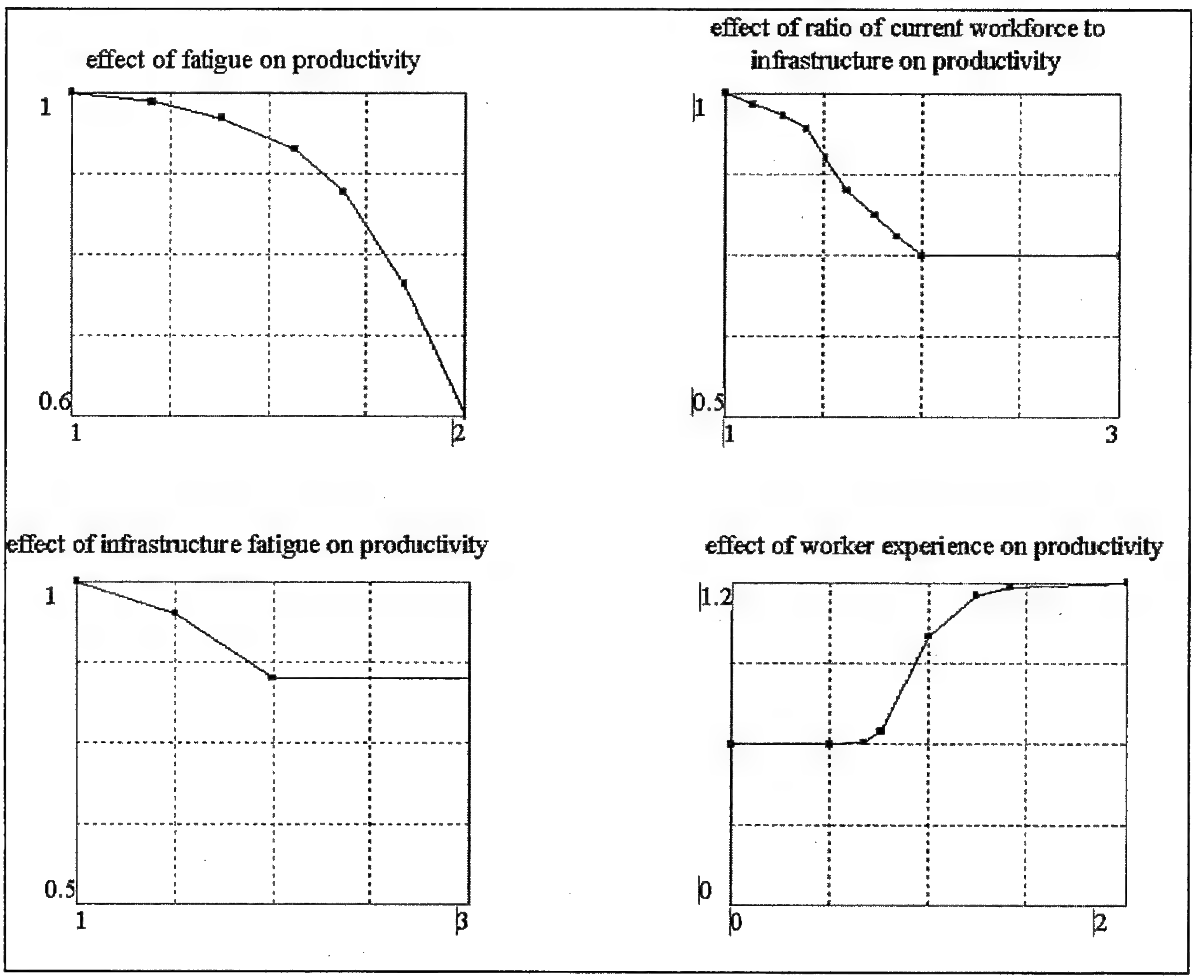

Figure 9: Productivity effect graphs

ERROR RATE

Five effects control the error rate. Four of them are shown in Figure 10. The graph not shown is *the effect of infrastructure fatigue on the error rate*, which was deemed to have no effect in the current environment by a consensus of the MSR community. This is due to the fact with historical loading the infrastructure capacity of the port shipyards has always had enough redundancy so as not to be a factor. Theoretically, should the workload levels increase dramatically over a prolonged period of time, the slow rate of infrastructure response may begin to impact the error rate as more equipment fails due to lack of required maintenance and support personnel become increasingly fatigued. Setting the value equal to one neutralizes this effect.

PORT CAPACITY GROWTH

Figure 11 show the non-linear functions that control the growth of port capacity. The rate of increasing port capacity realistically constrains the movement of potential new hires into the port area as discussed earlier.

ATTRITION

Attrition is nominally set at twelve percent per year for the shipyard. However the attrition varies as a function of fatigue and layoff reputation. These effects, as shown in Figure 12, are the *effect of worker fatigue on quality of the workforce* and the *effect of industry reputation on the quality of the workforce.*

WORKFORCE DISSIPATION

Personnel cannot be expected to hang around indefinitely for recall after being laid off. The *nominal excess dissipation time* constant was estimated at 37 weeks based on the information provided by the shipyard's human resource specialists. This time varies as a function of the *industry reputation ratio* and is shown in Figure 13.

OVERHEAD (OH) COSTS

Southwest Marine provided proprietary cost data to calculate the following two effect graphs that adjust the man-day rate based on overloading and underloading in relation to annual volume. These effect graphs are not shown in this paper due to their sensitive nature. The two effects are:

- *effect of annual volume on variable portion of OH Costs*
- *effect of annual volume on semi-variable portion of OH Costs*

Another common term for semi-variable costs would be fixed costs. The annual volume is the dynamic annual running average of the *Estimated Work Required.*

FINANCIALS

The model calculates Total Cost based on the amount of work completed (labor costs) and material and other indirect costs.

Labor costs are computed using a dynamic manday rate that is recalculated weekly. The current manday rate is calculated from the *manday adjustment for workforce adjustment*, *charging for infrastructure change costs* and the *manday rate at optimum ratio* multiplied by the *Current Repair Activity Workforce.*

The accumulated costs associated with adjusting the workforce are charged back over thirteen weeks (one quarter.) The accrued infrastructure change costs are charged back over two years.

The manday rate at optimum ratio is essentially the base labor rate "loaded" by a multiple. The multiple is calculated by combining the Overhead Rate with Direct Labor, Overtime, Fee, General and Administrative costs (G&A), and Facilities

Cost of Money (FCOM.) This information as well as the pricing model used to calculate the loaded rate will not be described in this paper, as it is business sensitive.

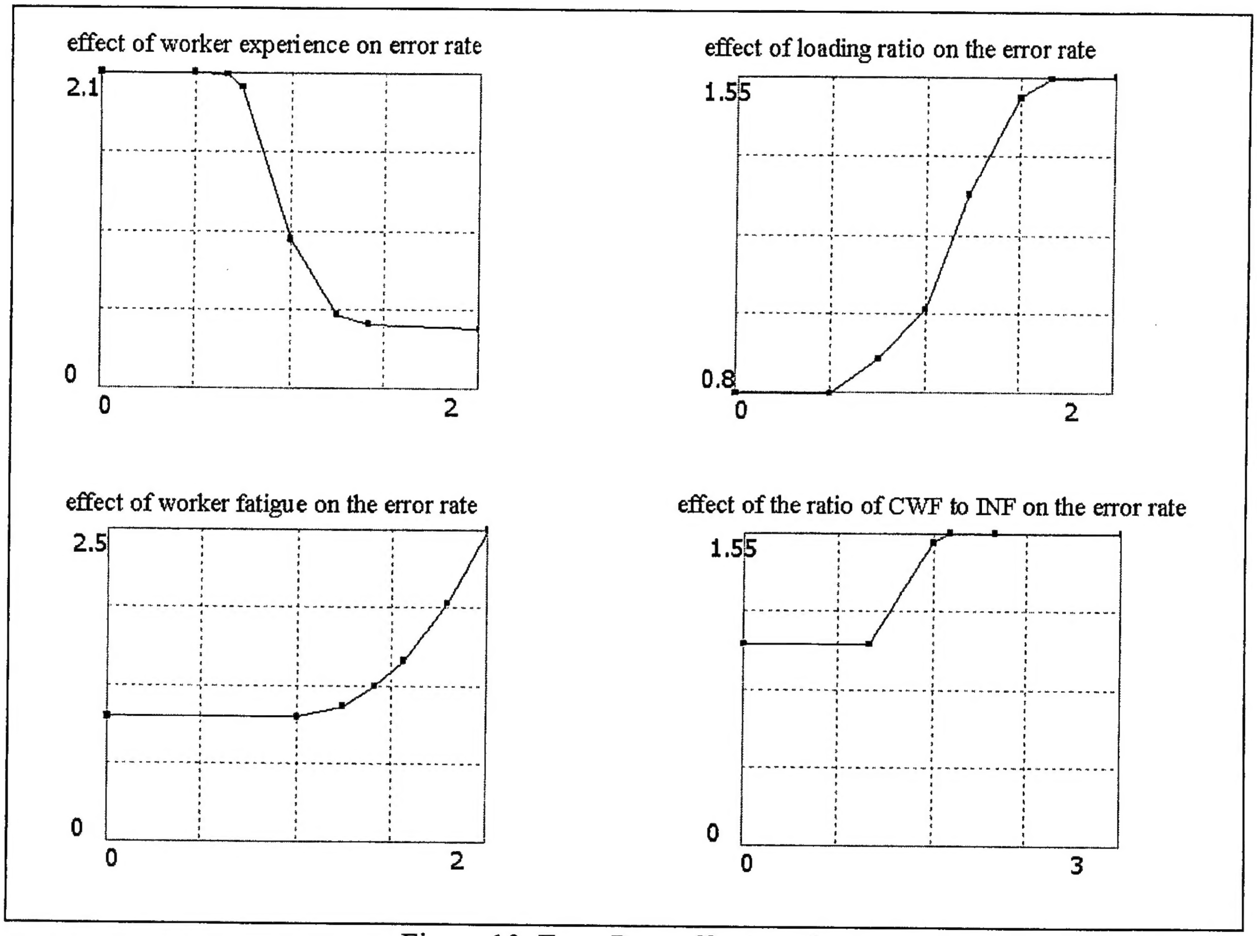

Figure 10: Error Rate effect graphs

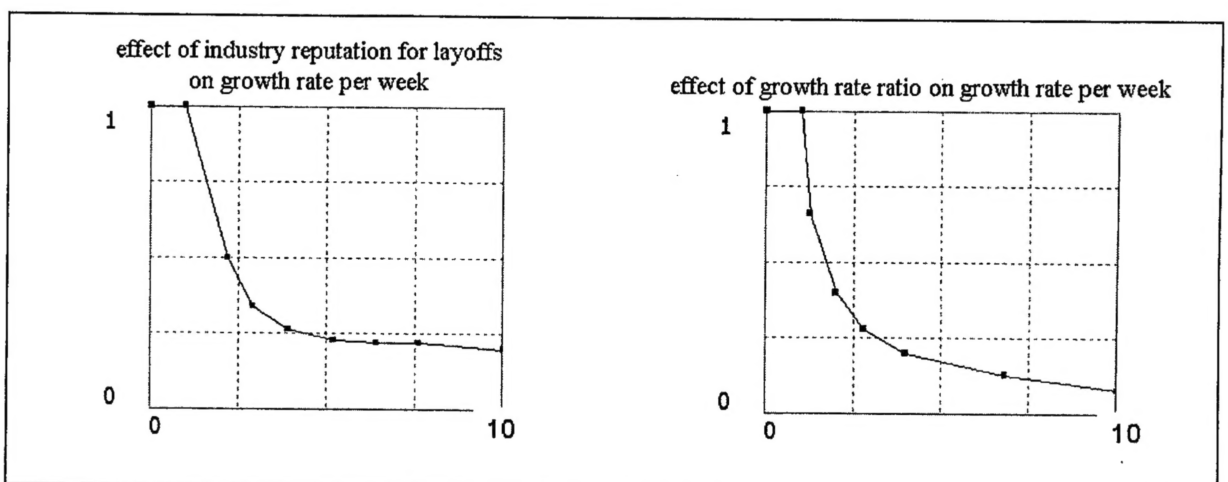

Figure 11: Port Capacity effect graphs

do that in the past, there was a reasonable expectation that predictions of future performance metrics would be accurate. It is important to note that to be useful those predictions need not be perfectly correct, only more correct than the predictions generated from current methods.

The testing consisted of configuring (or initializing) the model based on conditions as of a certain date. The model was run from October 2001 through the end of October 2002. Data and results were compared from the first week of April 2002 through the last week of October 2002 against historical data. There was an initial warm up period of 26 weeks to allow the model to stabilize. The model was then compared against historical data for the next thirty-one weeks. The model was run and results compared. Although numerous results were compared, two areas represented the most important metrics:

1. Workload
2. Workforce

Those results are shown in Figure 14.

RESULTS

- Correlation Coefficients (p):
- Workforce: 0.65
- Workload: 0.57
- Where n=31
- Degrees of freedom = 30
- $p > 0.55$ --> .001 Confidence

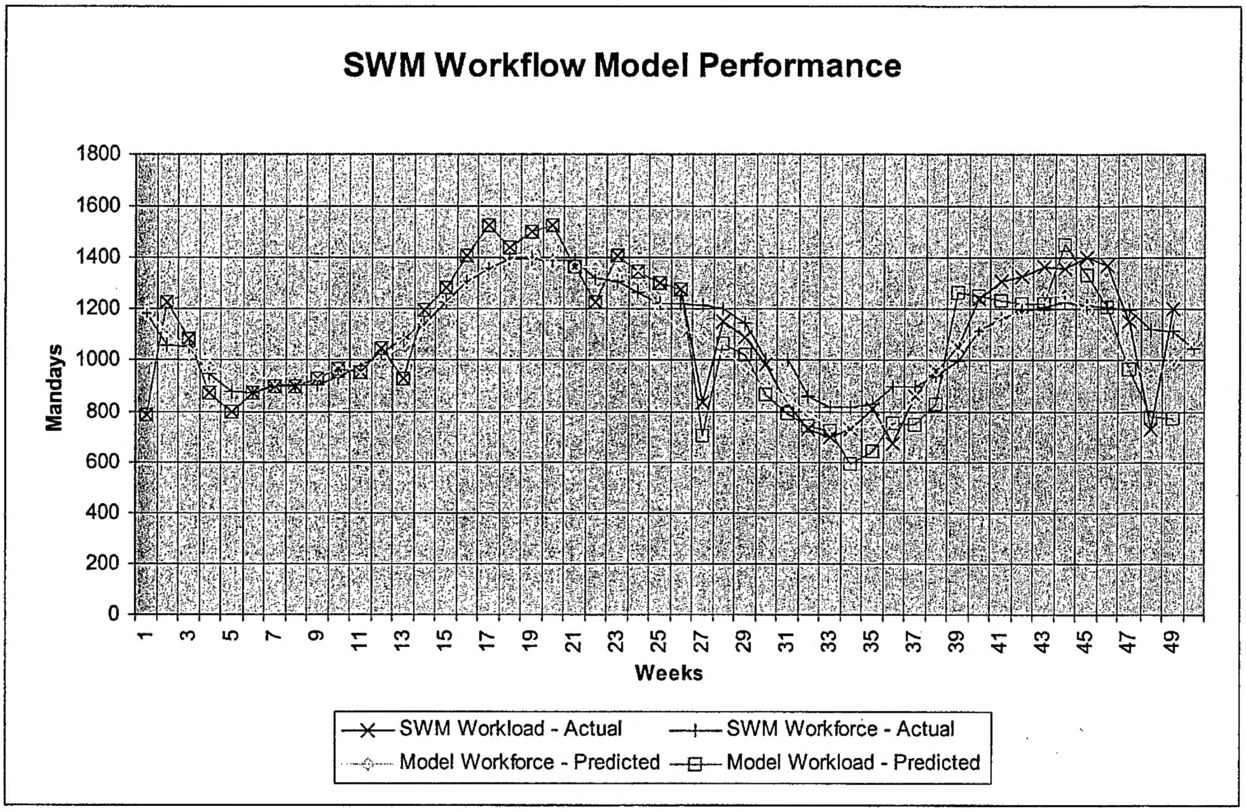

Figure 14: Comparison of Model Predictions vs. Historical Results

IMPLICATIONS AND MODEL USEFULNESS

Southwest Marine gained a useful tool that they use to better predict the impact on work and the workforce caused by the level and pattern of work given to them by the Navy. The insight it reveals helps them to not only better react, but to predict and prevent situations that cause disruptions in workload accomplishment and increases in cost. Although we were not able to talk much about cost, overall potential savings can be calculated based on workload reallocation. Level loading results in more work completed for less cost.

Of course, level loading reduces operational flexibility and the ship maintenance budget needs to be adjusted upwards during periods of high fleet activity that preclude a balanced workload for the shipyard. Smooth, gradual changes in workload maintain workforce stability, reducing needless cost due to churn and result in greater productivity with less rework.

SUMMARY

The ship repair workflow model demonstrates clearly the impact of work patterns on cost. An understanding of the effects of work pattern on productivity and error rate resulting in increased costs due to rework and unplanned overtime can then be used a planning tool for better estimates of future costs based expected work patterns.

Cooperative agreements and the establishment of trade centers in a port can be used to help shipyards in a port stabilize and smooth work patterns and reduce costs.

LIST OF ACRONYMS

COMNAVSURFPAC - Commander, Naval Surface Force U.S. Pacific Fleet
FCOM - Facilities Cost of Money
G&A - General and Administrative costs
HR - Human resources
MSR - Major Ship Repair
NAVSEA - Naval Sea Systems Command
OH - Overhead
SUPSHIP - Supervisor of Shipbuilding and Repair
SWM - Southwest Marine
USMR - United States Marine Repair

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NOTES:

[A] Notes on symbology: Figure 1 is a simplified "Stock and Flow" diagram. The rectangles represent stocks of things that accumulate over time. The valve symbols represent flows of things into and out of the stocks. Stocks (Levels) are fundamental to generating behavior in a system; flows (Rates) cause stocks to change. Arrows connect variables that control flows.